Population Patterns of Mexican Corn Rootworm (Coleoptera: Chrysomelidae) Adults Indicated by Different Sampling Methods

D. W. SPURGEON,[1] J. F. ESQUIVEL, AND C. P.-C. SUH

USDA–ARS, Areawide Pest Management Research Unit, 2771 F&B Road, College Station, TX 77845

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ABSTRACT The Mexican corn rootworm, *Diabrotica virgifera zeae* Krysan & Smith, is a serious pest of corn, *Zea mays* L., in several areas of Texas. Recent demonstrations of areawide adult control suggest this tactic has promise for rootworm management, but additional information regarding treatment thresholds and sampling methodology is needed. In 2000 and 2001 we examined the influence of distance into the field on rootworm captures by CRW and Pherocon AM traps, the fidelity of trap captures to population estimates from visual counts of beetles on plants (whole plant samples), and the seasonal population patterns indicated by each sampling method. Only the CRW trap consistently indicated reduced trap captures at the field margin compared with other distances. However, trends for the AM trap and whole plant samples suggested sampling on the field margin should be avoided. Population estimates at other distances into the field (2–30 m) were usually statistically similar. Thus, monitoring does not require trap placement far into the field. Both trap types indicated population peaks after flowering in corn, whereas plant samples indicated peak populations during tasseling and flowering. Both the CRW trap and plant samples showed the proportion of female beetles increased as the season progressed, but the CRW trap underestimated the proportion of females until after flowering. Regressions relating captures by traps to counts from plant samples indicated efficiency of both traps increased with increasing plant development. Our findings should increase acceptance of the CRW trap by producers and consultants and provide a rationale for development of improved, plant growth stage-specific treatment thresholds.

KEY WORDS *Diabrotica virgifera zeae*, trapping, corn rootworm, sex ratio, crop phenology

THE MEXICAN CORN ROOTWORM, *Diabrotica virgifera zeae* Krysan & Smith, is a key pest of corn, *Zea mays* L., in several regions of Texas. Economical control of this pest can be particularly difficult to achieve in central Texas production systems characterized by a low-input, dryland culture of continuous corn. Historically, this production region has relied almost exclusively on soil insecticides for rootworm control, and even where corn can be rotated with sorghum, *Sorghum bicolor* (L.) Moench, the value of rotation has been questioned based on an earlier report of rootworm damage to first-year corn (Stewart et al. 1995). In 1996, the USDA–ARS initiated several areawide corn rootworm management demonstrations in cooperation with state universities. These demonstrations focused primarily on semiochemical-based adult control tactics intended to reduce adult rootworm population levels before substantial oviposition had occurred, thereby reducing the potential for damage by larvae in the subsequent year. Lingren (1999) reported promising results for this approach in central Texas, but questions remain regarding appropriate treatment thresholds and monitoring methods.

Treatment thresholds for adult Mexican corn rootworms used in the Texas Areawide Demonstration are largely based on experience. Lingren (1999) used a treatment threshold of 0.5 adult beetle per plant. Recently, a new kairomone-based trap (CRW trap, Trécé, Salinas, CA), which generally captures higher numbers of beetles than other trap designs (Whitworth et al. 2002), has been adopted by programs in Texas and other states, and the Texas treatment threshold has been correspondingly modified to 100 cumulative beetles per trap. However, relationships between population estimates by the CRW traps and those by other more conventional methods have not been adequately examined for the Mexican corn rootworm. Efficient utilization of this new trap and development of refined thresholds will require additional information regarding interpretation of trap captures and implementation of trapping systems. In particular, information regarding seasonal patterns of capture, trap efficiency in relation to crop phenology,

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[1] E-mail: spurgeon@usda-apmru.tamu.edu.

and appropriate spatial arrangements of traps is needed. Regarding the latter factor, Lingren (1999) concluded that CRW traps should be placed ≥10 m from the field border, but he did not evaluate captures by traps at distances between 0 and 10 m into the field. If traps can be appropriately positioned at distances of <10 m into the field, acceptance of this sampling tool by producers and consultants would be increased. Our objectives were to assess the influence of trap placement (distance from the field margin) on captures of Mexican corn rootworm adults by CRW and yellow sticky traps (Pherocon AM, Trécé), examine the fidelity of beetle captures by CRW and AM traps to population estimates based on visual counts of beetles on plants (whole plant samples), and determine the seasonal patterns of populations indicated by each sampling method relative to corn plant phenology.

Materials and Methods

Experimental Design. Experiments were conducted in four commercial corn fields near Granger, TX, in both 2000 and 2001. In 2000, corn was planted in fields ranging from 9 to 63 ha on 20 February (Fielder's Choice 9114, Adler 3500 RR) or 21 February (Adler 5250, Adler 3500 RR). In 2001, unusually cool and rainy weather in March extended the planting period and slowed plant growth in early plantings. Consequently, fields were planted on 27 February (Adler 4000 RR), 14 March (Adler 4000 RR), and 15 April (two fields, Adler 3600 RR). Fields in 2001 ranged from 10 to 30 ha. All plantings followed corn from the previous season except one field in 2000, which followed sorghum. All fields were planted to 0.76-m rows and were treated with soil insecticide applied in a 10-cm band over the row at planting (162 g [AI]/ha, Aztec 2.1G, Bayer Corp., Pittsburgh, PA). Beginning 2–3 wk before the experiments were initiated, plant development in the study fields was observed weekly, and a small number of root systems were excavated to determine whether rootworm pupae were present. Traps were established in each field the week after pupae were first detected (two fields on both 4 and 11 May 2000, and two fields on both 24 May and 7 June 2001), which also roughly corresponded to tasseling of the corn in both years.

Four sampling sites >50 m apart and >25 m from field corners were established in the margins of each field. Because corn plantings usually extended to fencerows, drainage ditches, and adjacent crops, each sampling site was selected based on the presence of adequate space for the entire series of trap distances, and accessibility in the form of a road, turnrow, or sod waterway. We avoided locating sites in portions of fields where, for example, two adjacent corn fields were separated by only a fence line. Within each sampling site six CRW traps, each baited with a kairomone lure (TRE 8275, 1500 mg 4-methoxy cinnamaldehyde, Trécé) and equipped with a toxic feeding pellet, were established in the plant row at distances as close as possible to 0, 2, 5, 10, 20, and 30 m from the field border. The traps corresponding to the different distances within a site were arranged in an arc extending into the field, with sequential traps being separated by 20 m. CRW traps were either suspended between plants at ear height on floral wires (2000) or were supported at ear height on a polyvinylchloride pipe standard (2001). Each CRW trap was accompanied by an unbaited Pherocon AM trap (Trécé) placed around the plant at ear height and at the same distance from the field margin. CRW and AM traps were separated by 5 m, and AM traps were replaced biweekly. Beetles were removed from the traps weekly at which time two whole plant samples corresponding to each trap pair were collected. These whole plants were separated from the AM trap by at least 5 and 10 m, respectively, and were at the same distance from the field border as the corresponding trap pair. Witkowski et al. (1975) reported that adults of the western corn rootworm, *Diabrotica virgifera virgifera* LeConte, were most active during 2–3-h periods after sunrise and before sunset, but Weiss and Mayo (1985) found the time of sampling did not consistently influence population estimates from whole plant samples. Because we could not complete our sampling activities during one of the daily periods of peak beetle activity, traps were serviced and whole plant samples were collected between 1000 and 1500 hours (CDT) on each sampling date.

Beetles collected from CRW traps were placed in labeled vials containing 70% isopropyl alcohol. Beetles from AM traps were counted and discarded in the field. The emphasis of whole plant inspection was to obtain accurate counts of beetles on the selected plants, but as many of these beetles as possible were also collected into vials of alcohol. After a plant was sampled, additional beetles not included in the count were collected from adjacent plants when possible to provide an increased sample size for determination of sex ratio and the extent of ovarian development. In the laboratory, beetles from the CRW traps were counted and sexed using the criteria of White (1977). Identification of males was often facilitated by the external presence of a spermatophore or partial exertion of the aedeagus. Beetles from whole plant samples were also sexed and females were dissected to determine ovarian stage by using the 1–5 scale of Cinereski and Chiang (1968).

Occasionally, samples from CRW traps were lost to predation by ants or grasshoppers. When the loss of beetles was estimated as >10% based on the presence of beetle parts (particularly elytra), the sample was discarded. When predation by ants was observed, hydramethylnon bait (Amdro, American Cyanamid, Parsippany, NJ) was applied to the soil surface and lower leaf collars of plants surrounding the trap.

Fields were sampled during the period spanning growth stages VT (tassel) to R6 (physiological maturity) for totals of 7 (2000) and 6 wk (2001). On each sampling date each site was assigned a plant stage classification based on the predominant stage of plant development by using the method of Ritchie et al. (1989). These classifications were used to designate the plant growth stage for each field on each date.

Because fields were sampled weekly and the rate of plant development varied among varieties and planting dates, only four of the eight fields were sampled at each of growth stages VT and R6. After the last sampling date in each field, plant populations were estimated based on counts of plants in two 6.55-m lengths of row in each sampling site.

Statistical Analyses. Respective influences of sample distance from the field margin and plant growth stage on adult rootworm population estimates were examined separately for each sampling method (CRW and AM traps, whole plant samples) by using mixed model analysis of variance (ANOVA) (PROC MIXED, SAS Institute 2001). Fixed effects in each model included distance, plant growth stage, and their interaction. Random effects included field, site within field, the growth stage-by-field interaction, and the distance-by-site within field interaction. Differences among levels of fixed effects and their interactions were identified using Tukey's adjusted *P* values corresponding to paired differences among the least-squares means (Littell et al. 2002).

Respective relationships between beetle captures by the CRW and AM traps and population estimates obtained from whole plant inspections were examined by analysis of covariance (ANCOVA) and linear regression (PROC GLM and PROC REG, respectively, SAS Institute 2001). Because the need for insecticide treatment is usually determined on the basis of a whole field, means of beetle captures for each combination of sample type, field, and plant growth stage were used as model inputs. Captures from the CRW traps at 0 m were omitted because analysis indicated beetle numbers at that distance were consistently lower than at other distances. Population estimates obtained from whole plant samples were converted to rootworm beetles (adults) per hectare by using the estimated plant populations for each field. The ANCOVA model examined the equality of slopes for respective plant growth stages and included trap capture (either CRW or AM) as the response variable, and plant growth stage, beetle population estimate (whole plant), and their interaction as independent variables. The beetle population estimate from whole plant sampling was used as the covariable. Based on these analyses, simple linear regressions were constructed to describe the relationships between captures by respective trap types and whole plant population estimates for each plant growth stage. Because of among-field variation in plant development and the weekly sampling interval, each plant growth stage was not represented by an equal number of population estimates. This was particularly true for plant growth stage R3, which tended to be of somewhat longer duration than other stages.

Estimates of the proportions of rootworm adults that were female were available for both the CRW traps and whole plant samples, and these were compared among distances and plant stages for each sampling method by using mixed model ANOVA (PROC MIXED, SAS Institute 2001). Because many whole plant counts were zeros, counts of beetles collected from pairs of plants associated with each trap pair were summed before analysis. The respective models were identical to those previously used to assess the influences of distance and plant growth stage on beetle captures, except the response variable was the arcsine-transformed proportion of beetles that were female (arcsine$\sqrt{\text{proportion}}$, Zar 1984). Also, because of a scarcity of beetles on the latest sample dates (growth stage R6), only data collected from stages VT through R5 were analyzed. Based on these results, an additional analysis was conducted comparing the proportions of beetles that were female between sampling types and excluding distance into the field as a factor. The model for this analysis was similar to the preceding model except the factor of sample type was substituted for distance. Results of analyses on transformed proportions are presented as untransformed means and standard errors.

Because knowledge of the seasonal reproductive phenology of female beetles may be important to efforts to improve treatment thresholds aimed at preventing oviposition, patterns of ovarian development were examined in relation to plant growth stage. Hill (1975) reported that the ovaries of active reproductive *D. v. virgifera* fluctuate between ratings of 3 and 4 (on the 1–5 scale of Cinereski and Chiang 1968). Therefore, we classified female beetles as having poorly developed (ratings of 1 or 2) or well developed ovaries (ratings of 3 or 4). Estimates of ovarian development were available only for beetles collected during the whole plant samples, so the arcsine-transformed proportions of female beetles with well developed ovaries were compared among plant growth stages by using PROC MIXED (SAS Institute 2001). To provide adequate sample sizes of dissected females, on each sampling date the proportion of females with well developed ovaries was calculated for each field, rather than for each distance within a site. The ANOVA model contained the fixed effect of plant growth stage (VT through R5), and the random effect of field. Differences among the least-squares means corresponding to levels of growth stage were identified using Tukey's adjusted *P* values as described previously (Littell et al. 2002). The extent of field-to-field variation in the ovary ratings was also examined using the likelihood ratio statistic (Littell et al. 2002). Untransformed means and standard errors are reported.

Results

Effect of Sampling Distance into the Field on Rootworm Captures. Differences in captures of adult *D. v. zeae* among trap distances into the field were not demonstrated for the AM trap ($F = 0.88$; df = 5, 201; $P = 0.496$; Fig. 1a) or the whole plant samples ($F = 0.35$; df = 5, 191; $P = 0.880$; Fig. 1c). The distance by growth stage interaction for the AM trap ($F = 0.62$; df = 30, 925; $P = 0.948$) indicated the absence of a distance effect was consistent among plant growth stages. However, this interaction for the whole plant samples ($F = 2.80$; df = 30, 947; $P < 0.001$) indicated the influence of sample distance into the field varied among plant growth stages. Comparisons of the least-

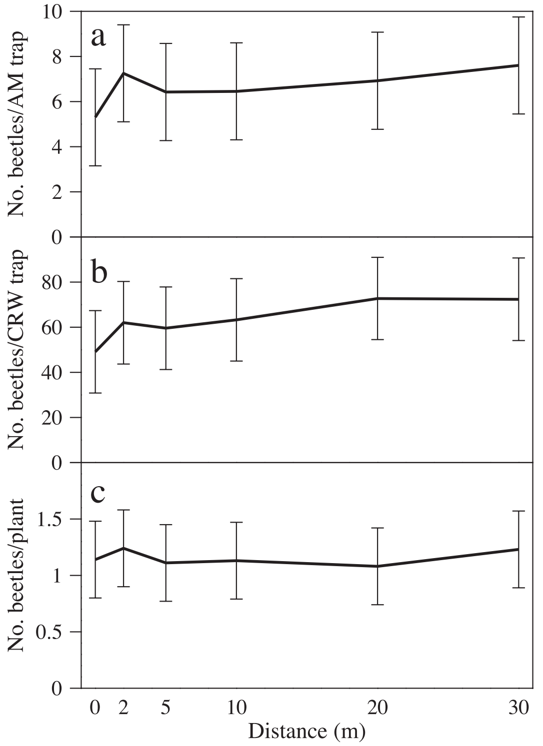

Fig. 1. Mean (±SE) captures of Mexican corn rootworm adults at various distances into the cornfield by Pherocon AM traps (a), CRW kairomone-baited traps (b), and whole plant samples (c).

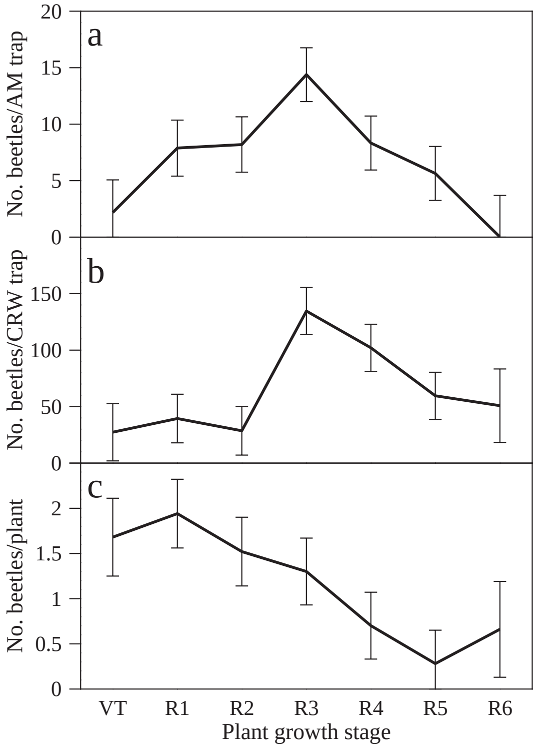

Fig. 2. Mean (±SE) captures of Mexican corn rootworm adults at different corn plant growth stages by Pherocon AM traps (a), CRW kairomone-baited traps (b), and whole plant samples (c).

squares means for combinations of distance and growth stage indicated that the distance effect was significant only during growth stages VT and R3. At stage VT, counts at the field border (0 m; 0.85 ± 0.52 beetles per plant) were lower than those at 30 m (2.86 ± 0.52 beetles per plant), and at stage R3, counts at the field border (2.30 ± 0.41 beetles per plant) were higher than at 2, 5, 20, and 30 m into the field (2 m, 1.14 ± 0.41; 5 m, 0.98 ± 0.41; 20 m, 1.03 ± 0.41; and 30 m, 0.88 ± 0.41 beetles per plant).

Captures by the CRW traps differed significantly among distances into the field ($F = 2.82$; df = 5, 201; $P = 0.048$), with captures on the field border being lower than those at 20 or 30 m (Fig. 1b). The distance by growth stage interaction for the CRW trap indicated the observed trap distance effect was consistent among plant growth stages ($F = 0.69$; df = 30, 898; $P = 0.895$).

Effect of Corn Plant Phenology on Rootworm Captures. All three sampling methods indicated significant differences in adult *D. v. zeae* population levels among plant growth stages (AM, $F = 5.61$; df = 6, 30.1; $P < 0.001$; CRW, $F = 8.20$; df = 6, 30.7; $P < 0.001$; whole plant, $F = 7.37$; df = 6, 29.8; $P < 0.001$; Fig. 2). Beetle captures by the AM trap peaked at growth stage R3 (Fig. 2a), whereas captures by the CRW trap peaked at stages R3 and R4 (Fig. 2b). In contrast, whole plant samples indicated beetle population levels during growth stages VT through R3 were higher than at stage R5, and populations at stage R1 were also higher than at stage R4 (Fig. 2c). However, the distance by growth stage interaction ($F = 2.80$; df = 30, 947; $P < 0.001$) indicated that the seasonal pattern of rootworm beetle occurrence indicated by whole plant samples varied among distances into the field. Whole plant samples taken at the field border indicated differences in beetle numbers only between growth stages R3 and R5 (R3, 2.30 ± 0.41; R5, 0.25 ± 0.42 beetles per plant). Samples taken from plants 2 m into the field did not detect seasonal differences in beetle numbers. Samples taken 5, 10, and 20 m into the field indicated differences in beetle numbers between growth stages R1 (5 m, 2.35 ± 0.44; 10 m, 2.02 ± 0.44; 20 m, 2.14 ± 0.44 beetles per plant) and R5 (5 m, 0.31 ± 0.42; 10 m, 0.25 ± 0.42; 20 m, 0.17 ± 0.42 beetles per plant). Samples taken 30 m into the field detected more differences among growth stages than did samples taken at other distances, indicating that beetle numbers were higher at growth stage VT than at stages of R3 through R5 (VT, 2.86 ± 0.52; R3, 0.88 ± 0.41; R4, 0.58 ± 0.42; R5, 0.36 ± 0.42 beetles per plant) and that counts at R1 (2.10 ± 0.44 beetles per plant) were higher than those at stage R5.

Relationships between Trap Captures and Whole Plant Samples. Analyses of covariance indicated slopes of regressions relating beetle captures by traps

Table 1. Regression parameters relating captures of adult Mexican corn rootworm by the Trécé CRW trap to population estimates (beetles per hectare) from whole plant samples for different corn growth stages

Growth stage	n	Slope (SE)	P	Intercept (±SE)	P	R^2
VT	4	0.00059 (0.00015)	0.06	−15.192 (13.615)	0.38	0.890
R1	7	0.00060 (0.00015)	0.01	−14.676 (17.653)	0.44	0.764
R2	9	0.00017 (0.00010)	0.14	14.078 (7.943)	0.12	0.284
R3	10	0.00172 (0.00029)	<0.01	37.917 (23.436)	0.14	0.815
R4	8	0.00258 (0.00044)	<0.01	17.226 (18.723)	0.39	0.850
R5	8	0.00367 (0.00086)	<0.01	13.003 (13.906)	0.39	0.754
R6	4	0.00064 (0.00269)	0.83	30.082 (35.689)	0.49	0.027

to population estimates from whole plant samples differed among plant growth stages for both the CRW and AM traps (whole plant by growth stage interaction; CRW, $F = 9.75$; df = 6, 36; $P < 0.001$; AM, $F = 2.85$; df = 6, 36; $P = 0.022$). Therefore, regressions between captures by respective trap types and population estimates from plant samples were calculated for each growth stage.

Significant relationships between beetle captures by CRW traps and population estimates from whole plant samples were detected for crop growth stages R1, and R3 through R5 (Table 1). Among stages for which significant relationships were demonstrated, slopes of the regression lines tended to increase with increasing crop development. Similarly, captures by AM traps were significantly related to whole plant population estimates for stages R2 through R5 (Table 2), and slopes of the regressions also tended to increase with increasing plant development. Neither trap produced beetle captures that accurately reflected population trends at early (VT, R1, and R2) and late (R6) reproductive stages of crop development, but both trap types provided useful estimates of beetle population levels during intermediate plant stages (R3 to R5). Based on R^2 values, fit of the regressions generally seemed slightly better for the CRW trap than for the AM trap.

Adult Rootworm Sex Ratios and Ovarian Development. The initial analysis of CRW trap captures indicated that observed proportions of beetles that were female were consistent among trap distances into the field ($F = 0.20$; df = 5, 178; $P = 0.964$). Overall, the proportions of females at different trap distances ranged from 0.752 ± 0.018 (30 m) to 0.777 ± 0.020 (5 m). The proportion of females also varied among plant growth stages ($F = 36.40$; df = 5, 34.7; $P < 0.001$; Fig. 3a). Female beetles represented the smallest proportion of the adult rootworm population in the earliest samples (VT, 0.382 ± 0.040), and this proportion increased as the plants developed until stage R3 (0.921 ± 0.027). The trap distance by growth stage interaction ($F = 1.06$; df = 25, 770; $P = 0.388$) indicated that observed changes among growth stages in the proportion of female beetles were similar at all trap distances.

Significant differences in beetle sex ratios among sample distances into the field were also absent for the whole plant samples ($F = 0.62$; df = 5, 524; $P = 0.681$). Overall, the proportions of beetles that were female in the whole plant samples at different distances ranged from 0.826 ± 0.043 (10 m) to 0.885 ± 0.042 (20 m). The whole plant samples also detected changes in the proportion of female beetles among growth stages (F = 7.58; df = 5, 23.3; $P < 0.001$; Fig. 3a), but until growth stage R3 the proportions of females indicated by plant samples were higher than those indicated by the CRW trap. Whole plant samples indicated the proportion of females was lowest at growth stage VT, but were statistically similar among the other growth stages (Fig. 3a). As for the CRW trap, the distance by growth stage interaction ($F = 0.88$; df = 25, 521; $P = 0.637$) failed to detect differences in the temporal changes in beetle sex ratios among sampling distances.

Because no differences in the proportions of female beetles were observed among distances within the respective sample types, sex ratios indicated by the CRW trap and whole plant samples were compared with respect to plant growth stage. In general, whole plant samples tended to indicate a higher proportion of females than did the CRW trap ($F = 25.45$; df = 1, 7.19; $P = 0.001$); however, the sample type-by-growth stage interaction ($F = 5.77$; df = 5, 66.4; $P < 0.001$) indicated the differences between sample types were not consistent at all growth stages. Examination of the

Table 2. Regression parameters relating captures of adult Mexican corn rootworm by the Pherocon AM trap to population estimates (beetles per hectare) from whole plant samples for different corn growth stages

Growth stage	n	Slope (SE)	P	Intercept (±SE)	P	R^2
VT	4	0.000016 (0.000043)	0.75	3.041 (4.017)	0.53	0.061
R1	7	0.000046 (0.000041)	0.31	3.516 (4.847)	0.50	0.201
R2	9	0.000081 (0.000031)	0.04	1.679 (2.375)	0.50	0.489
R3	10	0.000181 (0.000036)	<0.01	3.202 (2.907)	0.30	0.760
R4	8	0.000184 (0.000055)	0.02	2.154 (2.317)	0.39	0.651
R5	8	0.000375 (0.000062)	<0.01	0.566 (0.999)	0.59	0.861
R6	4	−0.000187 (0.000196)	0.44	5.881 (2.600)	0.15	0.312

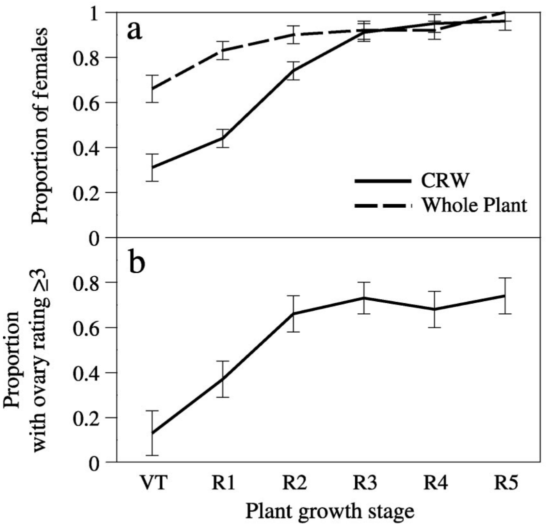

Fig. 3. Mean (±SE) proportions of Mexican corn rootworm adults that were female in captures by CRW kairomone-baited traps and whole plant samples at different corn plant growth stages (a), and proportions of female beetles with well developed ovaries from whole plant samples (b).

least-squares means indicated the proportions of females observed in the whole plant samples were higher than those observed for the CRW trap only from stage VT through R2. From stage R3 until sampling was terminated, the proportion of females indicated by the two methods were similar and consistently high (Fig. 3a).

The proportion of female beetles with well developed ovaries varied significantly among plant growth stages ($F = 7.57$; df = 6, 27.7; $P < 0.001$; Fig. 3b). On average, the degree of ovarian development increased from the first sampling date until growth stage R2; the proportions of females with well developed ovaries were statistically similar at stages VT and R1 but were higher at subsequent stages. The likelihood ratio test did not provide conclusive evidence of differences in ovary ratings among fields ($P = 0.061$).

Discussion

Tollefson (1986) recommended that placement of AM traps close to the field border should be avoided, but no specific information regarding appropriate trap placement was provided. Darnell et al. (2000) reported that sampling for *D. v. virgifera* on field edges should be avoided when the stage of crop development differs between adjacent fields, based on the preference of beetles for flowering corn. In our study, only the CRW traps consistently indicated reduced beetle captures at the field margin relative to captures at other distances. This pattern was also exhibited in whole plant counts in the earliest samples (growth stage VT), but no such pattern was detected for the AM traps. Still, numerical trends in captures of beetles by the AM trap (Fig. 1) suggest reduced captures on the field margin despite our inability to demonstrate these differences statistically. In general, our results are consistent with these earlier reports with regard to the need to avoid sampling on the field border. However, the data also suggest that for routine monitoring, it is not necessary to place traps or collect samples at distances of ≥10 m into the field as suggested by Lingren (1999).

Available information regarding seasonality of adult *D. v. zeae* populations is limited, but generally consistent with reports for *D. v. virgifera.* Lingren (1999) reported that adult *D. v. zeae* populations estimated by plant inspections were highest during flowering, whereas captures on sticky and kairomone-baited traps were lowest during this period. Thus, peak beetle population estimates occurred later for both trap types than for whole plant samples. Weissling and Meinke (1991) observed that counts of *D. v. virgifera* from whole plant samples were highest during flowering (stage R1) and subsequently declined. However, beetle response to kairomone-baited traps was comparatively low during the peak pollination period. Those authors suggested the low trap captures during flowering may have been caused by competition from volatiles produced by flowering corn plants. Similarly, Lance and Elliott (1991) found that responses of *D. v. virgifera* to kairomones were lowest when corn was flowering. Based on our results, both the CRW and AM traps indicate adult *D. v. zeae* population peaks later in the season than do whole plant counts. However, particularly during the early corn growth stages (VT–R2), the AM trap seems less sensitive to competition from plant structures than the CRW trap (Fig. 2). Whitworth et al. (2002) reported similar differences between whole plant counts and the CRW trap in *D. v. virgifera* population trends, although they did not provide information regarding plant growth stages that would facilitate direct comparisons with our data. The similarities between responses of *D. v. zeae* and *D. v. virgifera* were expected because Lance et al. (1992) reported similar responses to a number of kairomone baits by both species.

Our results regarding the relationships between captures of beetles by the two trap types and population estimates from whole plant samples also suggest competition between plant parts and the traps during the early plant growth stages. In particular, changes among plant growth stages in slopes of regressions relating respective captures by the CRW and AM traps to estimates from whole plant samples suggest an increase in trapping efficiency with increased plant development. These results contrast somewhat with those of Lance and Elliott (1991), who reported the efficiency of sticky traps for monitoring adult *D. v. virgifera* was not greatly influenced by plant phenology. However, those authors evaluated trap captures over a more restricted range of plant development than we observed. Shaw et al. (1984) reported a correlation between *D. v. virgifera* beetle captures by a cucurbitacin-baited trap and population estimates from whole plant samples when calculated over the entire trapping period, but they did not report the plant growth stages involved. Lingren (1999) reported a statistical relationship between captures of adult *D. v. zeae* by both AM traps and a kairomone-baited trap during 1 year of his study, but fit of those relationships was poor, and no relationship was detected from data collected the previous year. Those regressions were also calculated over the entire sampling period, and better model fit may have been possible with separate models for each plant stage.

A potential benefit of a separate model for each stage is the opportunity to devise growth stage-specific thresholds that account for changing trap efficiency. For example, considering that most of the females collected at growth stage R2 contained well developed ovaries and that this was one of the periods of lowest capture by the CRW trap, it seems likely that a treatment threshold appropriate for decisions at this stage would differ from one at R3 when beetle captures by the CRW trap were at a seasonal high.

The sensitivity of trap captures to plant developmental stage also has relevance regarding the reliability of population estimates. Karr and Tollefson (1987) and Whitworth et al. (2002) suggested that traps, which accumulate beetles over a period of time and different environmental conditions, may provide more reliable population estimates than plant samples taken at a point in time. However, the poor fidelity of beetle captures we observed by the AM or CRW trap at early plant stages, relative to estimates from the whole plant samples, suggests the reliability of the respective sampling methods may be conditional on plant stage.

Several investigators have observed the sex ratios of *D. v. virgifera* populations to become progressively biased toward females as the season advances (Shaw et al. 1984, Naranjo 1991, Weissling and Meinke 1991). There are also indications that the extent of this bias varies with sampling method. Godfrey and Turpin (1983) observed that sticky traps tended to underestimate the proportion of beetles that was female, relative to hand-collected samples of beetles. Similar observations were reported by Kuhar and Youngman (1995), but the proportions of females they observed were generally much lower than those we observed for *D. v. zeae.* Our results also indicate that captures by the CRW trap tend to underestimate the proportion of females until after growth stage R2. The factors responsible for these results are not clear, but may involve differences between the beetle sexes in the extent of competition between tassels and green silks and the CRW trap lure.

In summary, our results suggest trap-based efforts to monitor adult populations of *D. v. zeae* by producers and consultants do not require trap placement at substantial distances from the field margins. In that case, placement of traps <10 m into the field should reduce the time and effort associated with trap servicing. Also, our findings indicate that improved trap-based treatment thresholds could result from efforts to develop guidelines that account for plant stage-specific efficiencies of trapping methods and the seasonal patterns of female beetle reproductive phenology.

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